Rev Ind Organ (2017) 50:345–366
DOI 10.1007/s11151-016-9533-0

Pricing Strategies with Costly Customer Arbitrage

Hugh Sibly[1]

Published online: 14 July 2016

Abstract A monopolist's ability to conduct non-linear pricing is limited because customers can, at a cost, unbundle bundled output. Three pricing strategies are available to a firm: (1) a separating strategy; (2) a pooling strategy; and (3) an exclusion strategy. Each is optimal for some set of unbundling cost and distribution of customer types. The optimal pricing strategies are contrasted with the well-studied benchmark cases, in which unbundling costs are either zero or arbitrarily high. It is shown that it is not always possible to extrapolate the conclusions from the benchmark cases with respect to pricing, profitability, consumer surplus or efficiency.

Keywords Non-linear pricing · Pricing strategies · Unbundling

JEL Classification D42

This paper models a firm's pricing strategy in the presence of agents who can, at some cost, 'unbundle' bundled output, and who may then conduct arbitrage. Somewhat surprisingly, a systematic analysis of such a market has not been

Electronic supplementary material The online version of this article (doi:10.1007/s11151-016-9533-0) contains supplementary material, which is available to authorized users.

✉ Hugh Sibly
Hugh.Sibly@utas.edu.au

[1] Tasmanian School of Business and Economics, University of Tasmania, Private Bag 84, Hobart, TAS 7001, Australia

undertaken in the literature. The results of the analysis in this paper indicate that the presence of such agents can explain pricing behavior that is otherwise puzzling.

For instance, when one visits a supermarket, it is apparent that many items are physically bundled when sold. Soft drinks are often sold by the individual cans, but also in bundles of 6, 12, and 24. The Maskin and Riley (1984) model, in which customers are screened by type with the use of non-linear pricing, provides the standard explanation for this behavior. Yet it is equally apparent is that there are many goods that are not so bundled. For example, in the author's local supermarket canned fruit and vegetables, bottled sauces and pastes, and kitchenware items are all sold only as single units. There are literally thousands of other similar examples in supermarkets worldwide.

This observed pricing behavior is puzzling from the perspective of the Maskin and Riley (MR) model, as it predicts that producers *always* supply large bundles to high demand consumers. The costs that are associated with the *creation* of bundles cannot be a reason that large bundles are not supplied, as supermarkets could costlessly create a virtual bundle by offering consumers a menu of prices that are based on the number of items purchased.[1] Indeed supermarkets are often observed offering specials in which customers receive a discount if they purchase a second item.

In the model that is presented in this paper customers, who are one of two types, purchase discrete units of output. One type demands at most two units, while the other demands at most 1 unit. This specification of consumer preferences provides a tractable model to study unbundling. Specifically, the model is used to study the impact of changes in the cost of unbundling and on the distribution of customer types on the pricing strategy of firms. In contrast to much of the literature, the analysis does not assume that the volume of a type's demand is positively related to their marginal benefit.

Three potential equilibrium pricing strategies open to the firm: (1) a separating strategy; (2) a pooling strategy (the same bundle to both customer types); and (3) exclusion strategies (only sell to one customer type). It is shown that each of these strategies is optimal for the firm for some parameter values. The results of the model are contrasted with well-studied benchmark cases, in which unbundling costs are either zero (the standard linear-pricing monopolist) or arbitrarily high (as studied by Maskin and Riley 1984). It is shown that it is not always possible to extrapolate from the benchmark cases. For instance, unlike the benchmark cases, efficiency is non-monotonic in the unbundling cost for certain parameter values.

[1] The reader might be concerned that a unit is endogenous in some of the examples cited above (For example, the size of a can of fruit is determined by the manufacturer). However, irrespective of how a unit is determined, the puzzle identified here will occur if one or more customers are observed buying two single units. There is a profitable opportunity in such cases for virtual bundling (when unbundling is not possible). In addition, a unit is exogenous for many goods that supermarkets could virtually bundle but don't: e.g., mops, buckets, utility knives.

1 Literature

The literature has paid little attention to the consequences of unbundling. Alger (1999) also considers two customer types that can form collations (joint purchases that enable unbundling) but (unlike this paper) face zero transaction costs when making and dividing up joint purchases. Alger's analysis focuses on a separating equilibrium. In contrast to the usual conclusions of mechanism design, Alger shows that joint purchases ensure that both consumer types receive strictly positive utility, the quantities in both types' bundles are downwardly distorted, and the firm's profit is lower.

McManus (2001) shows that a firm that utilizes two-part tariffs may benefit from customer coalition formation, as between-customer arbitrage allows it to capture more consumer surplus as profit. Gans and King (2007) present a model in which the firm may utilize perfect price discrimination even when consumer arbitrage is possible. Their model's assumptions differ from the present one in that: (1) each of the two customer types has only one unit of demand; and (2) the firm is uncertain as to the proportion of customers that are of a given type.

Resale of a monopolist's output has been considered in different contexts: Hammond (1987) considers a continuum economy in which goods are costlessly exchangeable. In general equilibrium goods must be sold at linear prices: the exchangeability undermines non-linear pricing. Aguirre and Espinosa (2004) consider the impact of consumer arbitrage in a linear city model with convex transportation cost. Calzolari and Pavan (2006) consider pricing mechanism for a monopolist that sells a durable good that can be resold in a secondary market. A considerable literature has developed with respect to auctions with resale (see for example Zheng 2002).

2 Unbundling

A monopolist produces output in identical discrete units and has, for simplicity, zero fixed and marginal cost. The firm can bundle output. A bundle of two can be 'unbundled' by an agent (unbundler) into single units at a cost of α per unit (or 2α per bundle).

The activity of unbundling can be thought of as being undertaken in one of two ways: in the first, two customers could jointly purchase one bundle, and divide it between them. This is the type of unbundling that is considered by Alger (1999). For instance, two academic colleagues might decide to purchase jointly and share a large package of coffee rather than separately purchase small packages of coffee. This joint purchase would involve coordination costs: for example, the coordinating costs of who would purchase the coffee, and the time and effort that are involved in dividing or finding a way to share the coffee. In the following model it is assumed that the customers equally share the cost of the package and unbundling cost.[2]

[2] Note that it is not necessary to restrict joint purchases to customers within a type as does Alger.

Alternatively, it might be assumed that a perfectly contestable market for unbundled output might arise if arbitrage possibilities exist. Unbundlers in this market have an average cost per unbundled unit of α.

In either case, if a two-unit bundle was sold for a price of T^2, a customer can obtain unbundled output at a per unit price of $P^U \equiv T^2/2 + \alpha$. Call P^U the unbundled price.

3 One Customer Type

We consider the cases in which the firm has one (high-volume) customer type in this section, and then extend the analysis to the case in which it has two (high- and low-volume) customer types in the following section. Each of the N^H identical 'high-volume demand' (indexed $i = H$) customer types has marginal benefit (MB):

$$MB^H(X) = \begin{cases} U_1^H & if \quad X = 1 \\ U_2^H & if \quad X = 2, \\ 0 & otherwise \end{cases} \tag{1}$$

where X is the number of units that are consumed by the customer and $U_1^H > U_2^H > 0$. The MB of the consumer is depicted in Fig. 1a. Further assume that U_1^H is the monopoly price under linear pricing. This assumption parallels the usual result with divisible output that the efficient price under linear pricing (U_2^H) is less than the monopoly price (U_1^H). It is useful below to define $\alpha^1 \equiv (U_1^H - 2U_2^H)/2$. As $2\alpha^1$ is the difference between per-person profit when the per-unit price is U_1^H and

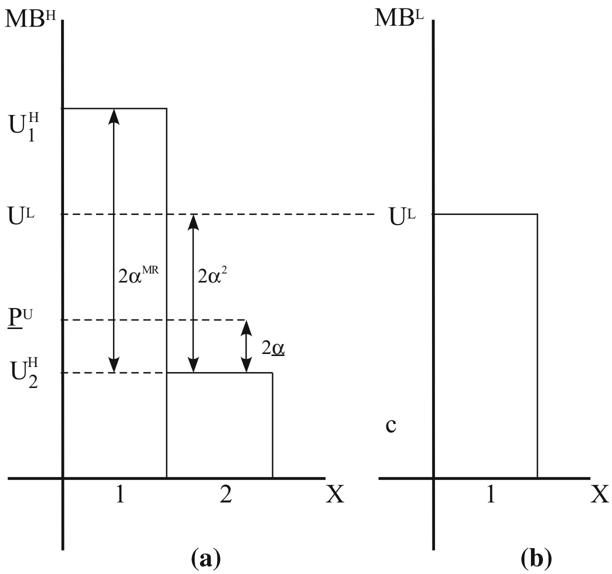

Fig. 1 Marginal benefits. **a** Type H. **b** Type L

when it is U_2^H, the assumption that U_1^H is the monopoly price under linear pricing ensures that $\alpha^1 > 0$.

When all of the firm's customers have MB given by (1), it has two prospective profit-maximizing strategies: (1) strategy E_1, where the firm sells one unit at price U_1^H; or (2) strategy E_2, where the firm sells bundles containing two units at a bundle price of T^2.[3] Assume for simplicity that the process of bundling is costless to the firm.

In order to sell 2-unit bundles, the firm must set the 2-unit bundle price so that customers do not purchase single unbundled units. Customers will only purchase bundled output from the firm if, by doing so, they gain at least as high consumer surplus (CS) as from purchasing unbundled output. Specifically the CS from bundled output is greater than unbundled when:

$$U_1^H + U_2^H - T^2 \geq U_1^H - \left(T^2/2 + \alpha\right) \Leftrightarrow T^2 \leq 2\left(U_2^H + \alpha\right). \tag{2}$$

From (2), the price of bundled output must be sufficiently low to deter the purchase of unbundled output.

The firm is thus constrained to set the bundle price less than the upper bound, $2(U_2^H + \alpha)$, given by (2) or the customers' total benefit. On the assumption that $2(U_2^H + \alpha) < U_1^H + U_2^H$, the profit maximizing bundle price that deters unbundling is given when (2) holds with equality. In this case the optimal price of bundled output is:

$$T^2 = 2\left(U_2^H + \alpha\right) \Rightarrow P^U \equiv T^2/2 + \alpha = U_2^H + 2\alpha. \tag{3}$$

Note that an increase in the unbundling cost reduces the consumer surplus that is available from unbundled output, thereby allowing the firm to increase the (2-unit) bundle price. Therefore, if (3) holds, unbundlers would not have scope to make a profit, and would not operate.

To demonstrate that the firm will not set a greater bundle price than given by (3), suppose that the firm did set such a bundle price. That is, suppose that T^2 is set such that:

$$U_1^H + U_2^H - T^2 < U_1^H - \left(T^2/2 + \alpha\right) \Leftrightarrow T^2 > 2\left(U_2^H + \alpha\right). \tag{4}$$

In this case the bundle price is sufficiently large that purchasing a bundle provides the customer less CS than one unit of unbundled output. Under these circumstances unbundlers would operate, and all customers would purchase one unit of unbundled output. The firm would sell N^H units at an average per unit price $T^2/2$. However, as the MB of 1 unit is less than the average benefit of two units ($T^2/2 < (U_1^H + U_2^H)/2 < U_1^H$), the firm would obtain higher profit by simply adopting strategy E_1 (setting a unit price of U_1^H). Intuitively it is in the interest of the firm to price so that no unbundling occurs, as profit is lost to unbundlers when this happens.

[3] The label E denotes "exclusion". It is shown in the next section that, when there are two customer types, these strategies are implemented if the firm does not sell to the low-volume customer type.

Observe from (3) that as the unbundling cost increases so does the unbundled price. The following proposition indicates that the optimal pricing strategy will change in response to changes in unbundling cost:

Proposition 1 *If*:

1. $0 \leq \alpha < \alpha^1$ *the firm does not bundle its output and sets a unit price*, U_1^H;
2. $\alpha^1 < \alpha < \alpha^{MR}$ *the firm bundles its output and sets the bundle price at a level that is given by* (3), *and* $T^2 < U_1^H + U_2^H$; *or*
3. $\alpha \geq \alpha^{MR}$ *the firm bundles its output and sets* $T^2 = U_1^H + U_2^H$.

where $\alpha^{MR} \equiv (U_1^H - U_2^H)/2$.[4]

Observe that α^{MR} is the unbundling cost that causes $P^U = U_1^H$; i.e., that causes the unbundled price to be equal to the MB of the customer's first unit.

When the unbundling cost is very high ($\alpha \geq \alpha^{MR}$), unbundling is too expensive to be worthwhile, and the firm sells customers two units at a bundled price that is equal to their willingness to pay. This case corresponds to those textbook analyses in which firms use block pricing because unbundling is assumed impossible. The case in which the unbundling cost is low ($\alpha < \alpha^1$) corresponds to the textbook case in which the firm must use linear pricing. In such cases the unbundled price is close to U_2^H, and revenue from the bundled output is corresponding low. Thus it is profit-maximizing for the firm to sell one unit to each customer for the (assumed) optimal linear price of U_1^H (strategy E_1).

For moderate unbundling cost ($\alpha^1 < \alpha < \alpha^{MR}$) the firm sells each customer a bundle for the price, T^2, given by (3) (strategy E_2). In this case T^2 is sufficiently high that it is optimal for the firm to bundle output rather than to use linear pricing, even though it can't use non-linear pricing to extract customers' entire consumer surplus as profit. Note that the bundling cost α^1 results in the profit from strategy E_1 and strategy E_2 being equal: the firm is indifferent between linear pricing and bundling.

Consider an incremental increase in U_1^H, which is analogous to an incremental increase in the slope of a continuous demand curve. This change will yield an incremental increase in both α^{MR} and α^1 (because it increases the difference between the customer's marginal benefit of the first and second unit). Thus the set of unbundling costs for which the prospect of unbundling constrains the firm's ability to use non-linear pricing also increases.

An implication of Proposition 1 is that, when there is a moderate unbundling cost, the firm does not increase profit as a result of this increase in U_1^H, even though the firm is using non-linear pricing. The prospect of unbundling constrains the firm from raising its price, as is shown by (3). Intuitively, the increase in U_1^H increases the CS associated with bundled and unbundled output equally. Thus the firm is unable to raise the bundle price to capture, as profit, the increase in CS.

Proposition 1 also has some straightforward implications for profit, efficiency, and CS. Profit is constant in unbundling cost for $0 \leq \alpha < \alpha^1$, and increasing in

[4] This critical value of α is denoted with the superscript *MR* because the firm bundles output for $\alpha \geq \alpha^{MR}$ as is assumed by Maskin and Riley.

unbundling cost for $\alpha^1 < \alpha < \alpha^{MR}$. Note that, it is efficient to supply 2 units to each customer, as $U_2^H > 0$. Hence, as bundling is efficient (generating zero deadweight loss), Proposition 1 implies that production is inefficient for $0 \leq \alpha < \alpha^1$ and efficient for $\alpha \geq \alpha^1$.

These conclusions on profit and efficiency might have been expected given the corresponding results in the textbook cases. However the result for CS cannot be extrapolated in this way. Observe that CS is zero for $\alpha < \alpha^1$ and $\alpha > \alpha^{MR}$. However CS jumps if α increases incrementally above α^1, and is positive, and decreasing in unbundling cost, for $\alpha^1 < \alpha < \alpha^{MR}$. This jump in CS is a result of the firm's switch from strategy E_1 (which provides customers with zero CS) to strategy E_2 (which, because the firm's price is constrained by unbundling, provides customers with positive CS). This suggests that, in general, CS may be higher when output is bundled and unbundling cost has intermediate values than under linear pricing.

4 Two Customer Types

In this section there are two types of customers; types are identified by a superscript: type H, the high volume demand customers, have MB given by (1). Type L, the low volume demand customers, have MB:

$$MB^L(X) = \begin{cases} U^L & if \quad X = 1 \\ 0 & otherwise \end{cases}. \tag{5}$$

Type L customers demand up to 1 unit. The MB of type L customers is depicted in Fig. 1b. There are N^i type i customers $i \in \{H.L\}$. Let $n = N^H/N^L$.[5]

From Fig. 1 it is readily observed that that there are two qualitatively different relationships between the customer types' MB curves: one in which $U_1^H > U^L > U_2^H$ and the other in which $U^L > U_1^H$. Denote the former relationship between MB curves as 'intermediate L MB' and the latter as 'high L MB'.[6] In this section we consider separately the cases of intermediate L MB curves and high L MB. An additional case in which type L customers have low MB, $U_2^H > U^L$, is considered in the online appendix to this section, which can be found at: http://ssrn.com/abstract=2800822

4.1 Intermediate L MB: $U_1^H > U^L > U_2^H$

When $U_1^H > U^L > U_2^H$, four types of pricing strategies are open to the firm. In two of these strategies the firm sells to both customer types. They are:

[5] Maskin and Riley note that their model of bundling is theoretically equivalent to the vertical differentiation that is studied by Mussa and Rosen (1978). Similarly, Deneckere and McAfee (1996) consider how firms may intentionally reduce the quality of their products to conduct vertical price discrimination. The results of this paper are, however, not easily applied to vertical product discrimination as consumers are not normally able to 'unbundle' a high-quality product into two or more low-quality products.

[6] Customers have two actions they can undertake (purchase bundled or unbundled), and firms have one instrument (the bundle). Hence we are considering a multidimensional screening problem. (Rochet and Choné 1998). Consumer preferences satisfies the single crossing property for intermediate L MB.

1. The separating strategy, denoted Strategy S, in which the firm offers a pricing menu that results in bundled output that is sold to type H customers and a single unit that is sold to type L customers.
2. The pooling strategy, denoted strategy P, in which the firm sells one unit to both types.

The firm sells only to type H customers in the remaining two strategies. These strategies correspond to the two exclusion strategies that were discussed in the previous section, specifically:

3. Exclusion strategy 1, denoted strategy E_1, in which the firm only sells one unit to type H customers.
4. Exclusion strategy 2, denoted strategy E_2, in which the firm only sells two units to type H customers.

Observe that it is not possible for the firm to construct a pricing strategy that would result in sales made exclusively to type L customers, as a type H customer would always be willing to purchase a unit sold at a price that type L customers would be willing to pay. Hence the above four pricing strategies are the possible ones available to the firm.

To characterize the profit-maximizing strategy it is first necessary to identify the optimal separating strategy. If we utilize the revelation principle, it is necessary only to consider constraints that generate incentive compatibility. Specifically, a separating strategy requires bundles of two units that are targeted at type H customers (each of whom consumes both units and does not unbundle) and a single unit that is targeted at type L customers. To enact this strategy, type H customers must choose to purchase the bundle rather than the single unit; i.e., type H customers to receive a higher CS by doing so:

$$U_1^H + U_2^H - T^2 \geq U_1^H - T^1 \Leftrightarrow T^1 \geq T^2 - U_2^H, \tag{6}$$

where T^i is the price that is charged for bundle $i \in \{H.L\}$. Equation (6) is the analogue of the self-selection constraint that is considered by Maskin and Riley (1984). Type L customers satisfy their participation constraint:

$$T^1 \leq U^L. \tag{7}$$

Equation (7) is the analogue of the participation constraint in Maskin and Riley (1984).

In addition to the standard self selection and participation constraints, the firm must deal with the constraints that are imposed by the prospect of customers' purchasing unbundled output. The firm must set prices so that type H customers self-select bundled output over unbundled output. To do so, type H customers must receive greater CS from purchasing the bundled output than from purchasing the single unit. This condition is written as:

$$U_1^H + U_2^H - T^2 \geq U_1^H - P^U \Leftrightarrow T^2 \leq 2\left(U_2^H + \alpha\right). \tag{8}$$

Equation (8) is identical to (2) as both equations are constraints that are imposed on the firm by the purchasing decisions of customers with MB given by (1). Type L customers must similarly receive greater CS from purchasing the single unit from the firm at price U^L rather than unbundled output. Thus:

$$U^L - T^1 \geq U^L - P^U \Leftrightarrow T^1 \leq T^2/2 + \alpha. \tag{9}$$

Note that if (9) holds, and $P^U \leq U^L$, then the participation constraint (7) also holds.

Type H customers could potentially make multiple purchases of the single unit that is targeted at type L customers. The firm can ensure that type H customers purchase the bundle rather than two single units (as required by the separating strategy) if prices are such that:

$$U_1^H + U_2^H - T^2 \geq U_1^H + U_2^H - 2T^1 \Leftrightarrow T^1 \geq T^2/2. \tag{10}$$

That is, the 2-unit bundle price must be less than or equal to the price of two single units.

The following lemma specifies the profit-maximizing separating strategy, given that the firm faces the constraints (6)–(10):

Lemma 1 *With intermediate L MB, the profit-maximizing separating strategy satisfies*:

$$T^2 = 2\left(U_2^H + \alpha\right) \quad \text{and} \quad T^1 = P^U \quad \textit{if} \quad 0 \leq \alpha < \alpha^2 \tag{11}$$

or:

$$T^2 = U_2^H + U^L \quad \text{and} \quad T^1 = U^L \quad \textit{if} \quad \alpha^2 \leq \alpha, \tag{12}$$

where $0 < \alpha^2 \equiv (U^L - U_2^H)/2 < \alpha^{MR}$.

To explain Conditions (11) and (12) note that, by (3), the unbundled price is positively related to the unbundling cost. When the unbundling cost is low—i.e., $\alpha < \alpha^2$ as is assumed in Eq. (11)—the unbundled price is less than U^L. In this case the prospect of unbundling imposes a binding constraint on the price of a single unit under a separating strategy. Figure 1 shows an example of this in which the unbundling cost, α, is less than α^2 and therefore the unbundled price, P^U, is less than U^L. In this case P^U is the maximum that can be charge for a single unit bundle price without unbundling occurring. As a result, under the conditions of (11), both customers receive positive CS. This result accords with Alger's (1999) finding.

When the unbundling cost is high—i.e., $\alpha > \alpha^2$, as is assumed in Eq. (12)—the unbundled price is greater than U^L, which is the maximum price that the firm can charge for a single unit under a separating strategy. Thus unbundling does not impose a binding constraint on the firm when it is designing the optimal separating strategy. In this case the firm need only concern itself with the standard self-selection and participation constraints when designing the optimal separating strategy. Thus the prices shown in (12) correspond with those found by Maskin and Riley (1984) for the optimal separating strategy.

The following proposition follows from Lemma 1:

Proposition 2 *Assume* $\alpha \geq \alpha^{MR}$. *Then, with intermediate L MB, the firm adopts strategy S (strategy* E_2*) if*:

$$n < (>) \frac{U^L}{U_1^H - U^L} \equiv n^{MR}, \tag{13}$$

where $n \equiv N^H/N^L$. *The bundle price under strategy S is given by (12) and the bundle price under strategy* E_2 *is* $T^2 = U_2^H + U_1^H$.

Proposition 2 identifies the equilibrium pricing strategies for high α. This result corresponds to equivalent result of Maskin and Riley (1984), who assume that unbundling is not possible.

In Proposition 2 the unbundling cost is sufficiently high so that customer unbundling is never worthwhile. The only binding constraints that are faced by the firm are the self-selection constraint (6) and type L customer's participation constraint (7). The requirement to satisfy these constraints lowers the profit that the firm can extract from type H customers. When the number of type L customers is sufficiently low, it is optimal to exclude type L customers, and extract all of type H's CS (see also Armstrong 1996). Proposition 1 implies that the firm bundles output under an exclusion strategy (strategy E_2).

Now consider the case in which $\alpha < \alpha^{MR}$. As shown by Proposition 1, in such cases α is sufficiently low that the possibility that consumers may unbundle output is a constraint on the firm's pricing. There are two sub-cases: (1) $\alpha^1 \leq \alpha^2$; and (2) $\alpha^1 > \alpha^2$. As the results in the two cases are qualitatively similar, only the case in which $\alpha^1 \leq \alpha^2$ is discussed in the text below, and the case in which $\alpha^1 > \alpha^2$ is discussed in the appendix.

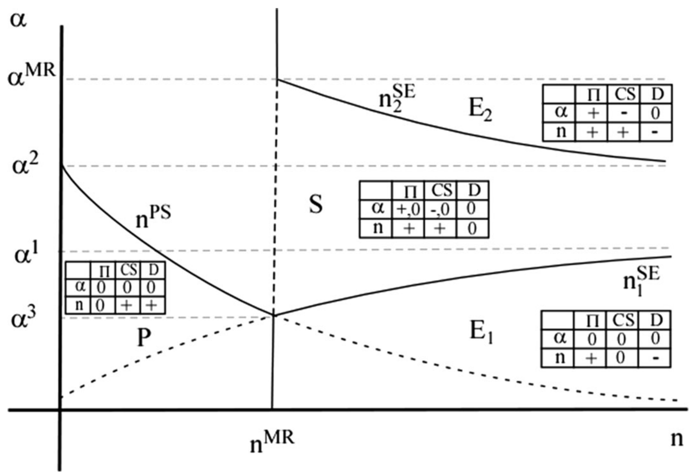

Fig. 2 Optimal strategies and their comparative statics with intermediate L MB and $\alpha^2 > \alpha^1$

In this section, for brevity, we also restrict attention to $U^L > 2U_2^H$. This assumption ensures that U_2^H is not the monopoly price under linear pricing; i.e., the profit-maximizing price under linear pricing is either U_1^H or U^L. This parallels the usual result with infinitely divisible output that the efficient price under linear pricing (U_2^H) is less than the monopoly price U^L. We retain the assumption that U_1^H would be the profit-maximizing price in the absence of type L customers (i.e., $\alpha^1 > 0$).

The relative profitability of each of the pricing strategies depends on the two key parameters: the ratio of type *H* to type *L* customers, and the unbundling cost. The regions that are depicted in Fig. 2 are the combinations of these parameters for which each pricing strategies is optimal. The tables that are embedded in Fig. 2 refer to comparative statics results within each region, and will be explained below.

To explain why the particular pricing strategy is optimal in its region in Fig. 2, it is first useful to first conduct a pairwise comparison of the profit under each strategy. The mathematical analysis of these pairwise comparisons is algebraically long and dense; therefore only an informal summary of the results is presented here. The formal mathematical results are presented in Lemma 2 in the online appendix.

The result of the pairwise comparisons of profit that are generated by the pricing strategies can be summarized, using Fig. 2, by the following description of Lemma 2:

Lemma 2 (Informal) *Assume* $\alpha^1 < \alpha^2$. *Then with intermediate L MB*:

1. *Strategy S yields greater (equal, lower) profit than strategy* E_r *if* $n <(=,>) n_r^{SE}$ *where* $r \in \{1, 2\}$.
2. *Strategy P yields higher (equal, lower) profits than Strategy S if* $n <(=,>) n^{PS}$.
3. *Strategy P yields higher (equal, lower) profits than strategy* E_1 *if* $n < (=,>) n^{MR}$, *where* n^{MR} *is given by* (13).[7]

The functional forms of the curves n_1^{SE}, n_2^{SE}, n^{PS}, and n^{MR} are derived in Lemma 2. Their representation in Fig. 2—in particular, their intercepts and slopes—are indicative. Note that the curves include both the solid lines and their dotted extensions.

The four curves that are shown in Fig. 2—n_1^{SE}, n_2^{SE}, n^{PS}, and n^{MR}—represent the sets of parameter values for which two pricing strategies yield identical profit. The labeling of three of the curves n_1^{SE}, n_2^{SE}, and n^{PS}—refers to the two pricing strategies that have equal profit.

Each of the curves—n_1^{SE}, n_2^{SE}, n^{PS}, and n^{MR}—divides the plane into regions in which one of the two strategies in the pairwise comparison generates higher profit. For example, strategy E_2 yields higher profit than strategy *S* above the curve n_2^{SE} because, from Proposition 1, the bundle price and profit under strategy E_2 is increasing in unbundling cost. However, by Lemma 1, the prices and profit under strategy *S* is independent of unbundling cost for $\alpha \geq \alpha^2$.

Now consider the position and slope of the curve n_2^{SE}. From Proposition 2 the point (n^{MR}, α^{MR}) lies on this curve. To explain the slope of n_2^{SE}, consider a small

[7] It is unnecessary to consider the pairwise comparison between strategy *P* and strategy E_2 (see Fig. 2).

decrease in unbundling cost from the point (n^{MR}, α^{MR}), which makes strategy S relatively more profitable than strategy E_2. The equality of profit from the two strategies can be restored by an increase in the proportion of type *H* customers, as this increases the firm's profit from strategy E_2 more than from strategy S. This is because each type *H* customer is more profitable under strategy E_2 than under strategy S. Similar reasoning can be applied to the interpretation, position, and slope of each of the three other curves in Fig. 2 that are introduced by Lemma 2. A detailed discussion of all of these possibilities is not presented as it would be repetitive.

The result of the pairwise comparison of profits in Lemma 2 is used in Proposition 3 to identify the circumstances under which each of the pricing strategies is most profitable:

Proposition 3 (Informal) *Assume* $\alpha^1 < \alpha^2$. *With intermediate L MB the optimal pricing strategies for given combinations of* (n, α) *are shown in Fig.* 2 *as the sets P*, S, E_1 *and* E_2 *bounded by the curves* n_1^{SE}, n_2^{SE}, n^{PS}, *and* n^{MR}.

The following reasoning is used to establish Proposition 3: consider, for example, the region in Fig. 2 above the curve n^{PS} and to the left of the line $n = n^{MR}$. In this region Lemma 2 shows that strategy *S* yields a higher profit than do strategies *P* and E_2, while strategy *P* yields a higher profit than does strategy E_1. Thus it can be concluded that strategy *S* yields the greatest profit in this region. By reapplying this process to all of the regions in Fig. 2, the way in which the optimal strategies depend on the unbundling cost and distribution of customer types is determined.

It is seen from Fig. 2 that each of the four possible pricing strategies (*P*, *S*, E_1 and E_2) is optimal for particular combination of unbundling cost and distribution of types. It is useful to define α^3 by $n^{PS} = n_1^{SE} = n^{MR}$. At the point ($n^{MR}$, α^3) the three pricing strategies *P*, *S*, and E_1 each yield the same profit.

The well understood 'benchmark' cases in which $\alpha = 0$ (linear pricing) and $\alpha > \alpha^{MR}$ (Maskin and Riley 1984) are incorporated in Fig. 2. In both cases exclusion is the optimal strategy for values of $n > n^{MR}$, as the firm is forgoing profit from the relatively large number of type *H* customers in order to sell to the relatively small number of type *L* customers. By contrast when $n < n^{MR}$ the firm would want to sell to the relatively numerous type *L* customers; hence strategy *P* is optimal when $\alpha = 0$, and strategy *S* is optimal when $\alpha > \alpha^{MR}$.

To understand the intuition behind why the strategies are optimal in the particular regions in Fig. 2, note from Lemma 1 that the two unit bundle price and thus profit increase with unbundling cost under strategy *S* (for $\alpha < \alpha^2$), while price and profit are independent of unbundling cost for strategies E_1 and *P*. Consider the impact on profit as the unbundling cost increases from 0 to α^{MR}. Under the benchmark case of $\alpha = 0$, either strategies *P* or E_1 dominate strategy *S*. But as α increases, so does profit under strategy *S*. Above the boundaries n^{PS} and n_1^{SE} strategy *S* is more profitable than strategy *P* or E_1. As was discussed above, profit becomes higher under strategy E_2 than under strategy *S* when α is above the curve n_2^{SE}.

Profit is thus non-decreasing in α, as it increases with α in regions S and E_2, and is independent of α in regions E_1 and P.[8] Similarly profit increases in n (holding population constant). Both of these conclusions are consistent with the equivalent result in the benchmark cases.

It can be seen from Fig. 2 that for intermediate values of α, such that $\alpha^3 < \alpha < \alpha^{MR}$, the transition between strategies differs as n differs from the benchmark cases. In particular, exclusion is not optimal for large n when $\alpha^1 < \alpha < \alpha^2$. As noted above, the prospect of unbundling makes exclusion suboptimal for these values of α when n is large. Further, pooling is optimal for $n < n^{PS}$, and strategy S is optimal for $n > n^{PS}$; this is a pattern that is not observed in the benchmark cases. Similarly for $\alpha^3 < \alpha < \alpha^1$ the optimal strategy transitions from pooling to separating to exclusion as n increases; this is again a pattern that is not observed in the benchmark cases.

Figure 2 can be used to identify the impact of an incremental increase in U_1^H. As was discussed in Sect. 3, an incremental increase in U_1^H incrementally increases both α^{MR} and α^1. However, it does not change α^2. An increase in U_1^H does not change the profit-maximizing prices, and hence does not change the firm's profit under strategy S (by Lemma 1), under strategy P, or (as described in Sect. 3) strategy E_2. However it does increase the price and profit under strategy E_1. Thus the curve n_1^{SE} shifts upward incrementally (in line with the increase in α^1) and n^{MR} decreases incrementally (as the exclusion strategies in the benchmark cases become more profitable). The curves n^{PS} and n_2^{SE} are left unchanged. Thus the main effect of an incremental increase in U_1^H is to increase only the size of the set E_1 (and correspondingly reduce the size of the sets S and P), with profit increasing only for points within the set E_1.

The impact of an incremental increase in U^L can also be analyzed with the use of Fig. 2. By their definition, neither α^{MR} nor α^1 is affected by this change. However α^2 is incrementally increased. This incremental change in U^L will not change the price or profit under strategies E_1 and E_2. By Lemma 1, the increase in U^L does not change the price and profit either under strategy S for $\alpha < \alpha^2$ because the unbundled price is below U^L, and the firm must charge type L customers the unbundled price. It yields an increase in price and profit under strategy S only for $\alpha > \alpha^2$ as the unbundled price does not constrain the price to type L customers.

An increase in U^L also increases the price and profit under strategy P. Consequently both n^{PS} and n_2^{SE} will shift upward, but n_1^{SE} will not move. Additionally n^{MR} will be increased (as strategies in the benchmark cases become more profitable than exclusion strategies). Thus the main effect of an incremental increase in U^L is to increase the size of the set P and to reduce the size of the set E_2 in Fig. 2 (with a corresponding change to the set S), with profit and prices increasing under strategy P and strategy S when $\alpha > \alpha^2$. In the other regions in Fig. 2 prices and profit do not change.

To identify whether the benchmark results on CS and efficiency can be extrapolated to the general case, consider the following:

[8] This conclusion could also be obtained by noting that an increase in α relaxes the seller's problem; thus profit must be non-decreasing.

Observation 1 For a given combination of $\alpha \geq 0$ and $n \geq 0$:

(a) CS is: (1) higher under strategy S than strategy P for $0 \leq \alpha < \alpha^2$, and is equal for $\alpha, \geq \alpha^2$; (2) higher under strategy P than strategy E_1; and (3) higher under strategy S than under either strategy E_1 or E_2.

(b) Deadweight loss (DWL) is: (1) higher under strategy E_1 than under either strategy P or strategy E_2; and (2) zero under strategy S.

Clearly CS is zero under strategies E_1, so other strategies will yield a higher CS. CS is also higher under strategy S than under strategy P for $\alpha < \alpha^2$, because the unbundled price that is associated with a separating strategy is less than U^L. For $\alpha^2 > \alpha$, both strategy S and strategy P give each type H customer CS of $U_1^H - U^L$.

Under strategy E_1 nothing is sold to type L customers, and only one unit is sold to type H customers. Thus DWL is higher under strategy E_1 than under strategy P (where one unit is sold to both customer types) or under strategy E_2 (where two units are sold to type H customers). DWL is zero under strategy S as all of the units with a positive MB are sold. Thus strategy S is the most efficient of the pricing strategies.

The tables that are placed within each of the sets in Fig. 2 summarize the sign of marginal changes in CS and DWL (D) following marginal changes in α and n. In those tables a '+' sign indicates increasing, a '−' sign indicates decreasing, and 0 indicates constant. Under strategy S, profit is increasing in α for $\alpha < \alpha^2$ and constant for $\alpha > \alpha^2$, which is indicated by '+, 0′ in the table in Fig. 2. Similarly, CS under strategy S is decreasing in α for $\alpha < \alpha^2$ and constant for $\alpha > \alpha^2$, which is indicated by '−, 0′ in the table in Fig. 2. Together with Observation 1, these tables identify how CS and DWL vary with α and n.

At this point it is useful to consider the CS in the benchmark cases to facilitate comparisons with the general case. From Proposition 2, the total CS in the benchmark case when $\alpha \geq \alpha^{MR}$ is $N^H(U_1^H - U^L)$ for $n < n^{MR}$ and 0 for $n > n^{MR}$. It is readily shown that total CS also takes these values under linear pricing ($\alpha = 0$), where the firm sets a per unit price of U^L.

By reference to Observation 1 and Fig. 2, it is seen that these results in the benchmark cases do not extended to the general case. Consider the impact on CS of an increase in unbundling cost (holding n constant) when $n < n^{MR}$. An increase in α in region P does not change CS from $N^H(U_1^H - U^L)$ as the prospect of unbundling does not affect strategy P. By Observation 1, increases in α across the boundary n^{PS} cause a positive jump in CS. This is because the firm switches from a pooling strategy in which only type H customers receive CS to a separating strategy where both types receive CS (as $\alpha < \alpha^2$). Further increases in α cause the prices T^1 and T^2 to increase and thus CS to decline. When $\alpha = \alpha^2$, CS is again $N^H(U_1^H - U^L)$. Increases in α beyond α^2 do not cause any further change to CS (because the prices T^1 and T^2 are unaffected by the unbundling cost for these values of α). A similar argument applies for the case in which $n > n^{MR}$. CS is therefore higher in region S and E_2 in Fig. 2 than in the benchmark cases.

In contrast to the benchmark cases, for $\alpha^1 < \alpha < \alpha^{MR}$, CS is increasing in n as $n \to \infty$ (as type H customers receive more CS than type L customers under strategy S and, trivially, strategy E_2). Further, for $\alpha^3 < \alpha < \alpha^1$, the CS jumps twice as n is increased: first upwardly as the boundary n^{PS} is crossed, and the second downwardly to zero as the boundary n_1^{SE} is crossed.

Naïve extrapolation from the benchmark cases might lead to an expectation that an increase in α increases efficiency. Observe that efficiency is indeed non-decreasing in α for $n < n^{MR}$, as strategy S is efficient while strategy P is inefficient (as type H customers purchase only 1 unit). However efficiency is non-monotonic in α for $n > n^{MR}$, as strategy E_1 and strategy E_2 are inefficient (because a type H customer purchases only 1 unit in the former strategy, and a type L customer's demand isn't served in either strategy). This result contrasts with the naïve intuition that unbundling costs increase a firms' ability to conduct non-linear pricing and thereby improves efficiency.

In the benchmark cases, DWL is lower for low n ($n < n^{MR}$) than for high n ($n > n^{MR}$). However, by reference to Fig. 2, DWL is higher for low n ($n < n^{PS}$) than for high n ($n > n^{PS}$) for unbundling cost $\alpha^1 < \alpha < \alpha^2$ as strategy P imposes a positive DWL whereas strategy S generates zero DWL. For $\alpha^3 < \alpha < \alpha^1$, Observation 1 implies that efficiency is higher for intermediate values of n ($n^{PS} < n < n^{SE}$) than for high ($n > n^{SE}$) and low ($n < n^{PS}$) values of n. Again, this outcome cannot be extrapolated from the benchmark cases.

4.2 High L MB: $U^L > U_1^H$

When $U^L > U_1^H$, only three pricing strategies will be optimal for the firm. As above, if the firm sells to both customer types it can offer (1) strategy S, a separating strategy in which it offers a pricing menu that results in bundled output that is sold to type H customers and a single unit that is sold to type L customers; and (2) strategy P, a pooling strategy in which it sells one unit to both types. The firm could also sell exclusively to one customer type. The only exclusion strategy that would be optimal in this case is strategy E, which involves the firm's selling single units of output only to type L customers.[9]

The same procedure is used in this case to identify the optimal pricing strategy as was used in the previous section to identify the optimal pricing strategies for intermediate L MB. To begin the analysis, the optimal separating strategy is identified. The firm faces three self-selection constraints if it adopts a separating strategy: first, type L customers do not purchase unbundled output if (9) holds. Second (as with Eq. (10) for intermediate L MB), type L customers purchase a single unit of output (at price T^1), and not the two-unit bundle (at price T^2), if the single unit provides greater CS. Specifically:

[9] It is never optimal to sell exclusively to type H customers in this case, as such a strategy would be dominated by a strategy in which a single unit is also sold for the bundle price or U^L, whichever is lower.

$$U^L - T^1 \geq U^L - T^2 \Leftrightarrow T^2 \geq T^1. \tag{14}$$

Third, type H customers purchase the two-unit bundle, and not the single unit, if:

$$U_1^H + U_2^H - T^2 \geq U_1^H - T^1 \Leftrightarrow T^1 \geq T^2 - U_2^H. \tag{15}$$

It is also necessary that type H customers do not purchased unbundled output; i.e., that (8) holds. It is readily shown that Condition (8) is satisfied if both (9) and (15) hold. Thus (9) and (15) jointly ensure that that type H customers do not purchased unbundled output.

Let $\alpha^4 \equiv (U_1^H + U_2^H)/2 > 0$ and $\alpha^5 \equiv U^L - (U_1^H + U_2^H)/2 > 0$. Note for future reference that $\min\{\alpha^4, \alpha^5\} > \alpha^{MR}$. Observe also that $\alpha^4 > (<)\alpha^5$ is equivalent to $U^L < (>) U_1^H + U_2^H$. Thus if $\alpha^4 > \alpha^5$, the maximum total benefit that is available to a type L customer (U^L) is less than the maximum benefit that is available to a type H customer ($U_1^H + U_2^H$). For brevity, the discussion below is restricted to the case in which $\alpha^4 > \alpha^5$. The qualitatively similar case in which $\alpha^4 < \alpha^5$ is analyzed in the online appendix. Then:

Lemma 3 *Assume high L MB and $\alpha^4 > \alpha^5$. Suppose that the firm adopts a separating strategy. Then the profit-maximizing bundle prices are given by*:

$$\left(T^2, T^1\right) = \begin{cases} \left(U_1^H + U_2^H, U^L\right) & \text{if} \quad \alpha \geq \alpha^5 \\ \left(U_1^H + U_2^H, \quad \dfrac{\left(U_1^H + U_2^H\right)}{2} + \alpha\right) & \text{if} \quad \alpha^{MR} < \alpha < \alpha^5 \\ \left(2\left(U_2^H + \alpha\right), \quad U_2^H + 2\alpha\right) & \text{if} \quad \alpha < \alpha^{MR} \end{cases}. \tag{16}$$

If $\alpha > \alpha^5$, the unbundling cost is sufficiently high that unbundling does not constrain the firm's pricing. In this case the firm is able to set its price equal to the customer's maximum benefit (thus forcing both customer types on to their participation constraints), and satisfy the self-selection constraints. The assumption that $\alpha^4 > \alpha^5$ ensures that type H customers do not choose one unit and that type L customers do not choose the two-unit bundle. Thus, in contrast to the intermediate L MB case, in this case the self-selection constraints are not binding in the separating pricing strategy.

If $\alpha < \alpha^{MR}$, unbundling does constraint the firm's bundle price (as described in Sect. 3). Because the bundle price is sufficiently low, self-selection will also constrain the firm's price of a single unit. Consequently the participation constraint is not binding for both customer types.

The optimal pooling strategy requires the firm to set price $T^2 = T^1 = U_1^H$. An exclusion strategy, in which $T^1 = U^L$, may be optimal under high L MB if type L customers' willingness to pay is sufficiently high. However, it is never optimal to sell exclusively to type H customers. For any price of the bundle that satisfies Proposition 1, it is possible to find a price, T^1, that satisfies (14) and (15) and type L's participation constraint. Consequently, the only exclusion strategy that could be optimal is one that excludes type H customers.

To identify the optimal pricing strategy, we follow the procedure that was used above for intermediate *L* MB. First a pair-wise comparison of the profit that is generated by each of the pricing strategies is conducted. The result of these pairwise comparisons of profit generated by the pricing strategies can be summarized, with the use of Fig. 3, by the following description of Lemma 4:

Lemma 4 (Informal) *Assume* $\alpha^4 > \alpha^5$. *Then, with high L MB*:

1. *Strategy E yields greater* (*equal*, *lower*) *profit than strategy S if* $n <(=, >) n^{ES}$;
2. *Strategy P yields higher* (*equal*, *lower*) *profits than strategy S if* $n <(=, >) n^{PS}$; *and*
3. *Strategy P yields higher* (*equal*, *lower*) *profits than strategy E if* $n <(=, >) n^{PE}$.

The three curves—n^{ES}, n^{PS}, and n^{PE}—represent the sets of parameter values for which the two pricing strategies in the pairwise comparison yield identical profit. The labeling of the three curves refers to the two pricing strategies that generate equal profit. Each of the curves—n^{ES}, n^{PS}, and n^{PE}—divides the plane in Fig. 3 into regions in which one of the two strategies in the pairwise comparison generates higher profit. For example, strategy *S* generates greater profit than does strategy *E* above the curve n^{ES} because, from Lemma 1, the bundle price and profit under strategy *S* are increasing in the unbundling cost. The prices and profit under strategy *E* are independent of the unbundling cost.

The position and slope of the curves n^{ES}, n^{PS}, and n^{PE} as shown in Fig. 3 are indicative of their functional forms. For example, consider the position and slope of the curve n^{ES}. From Lemma 3, when $\alpha = \alpha^5$, the bundle price is the same under strategy *S* and strategy *E*. Consequently, when $n = 0$ and $\alpha = \alpha^5$, strategy *S* yields the same profit as strategy *E*. Thus the point $(0, \alpha^5)$ lies on the curve n^{ES}. To explain the slope of n^{ES} recall that if the unbundling cost is reduced, price and thus profit are

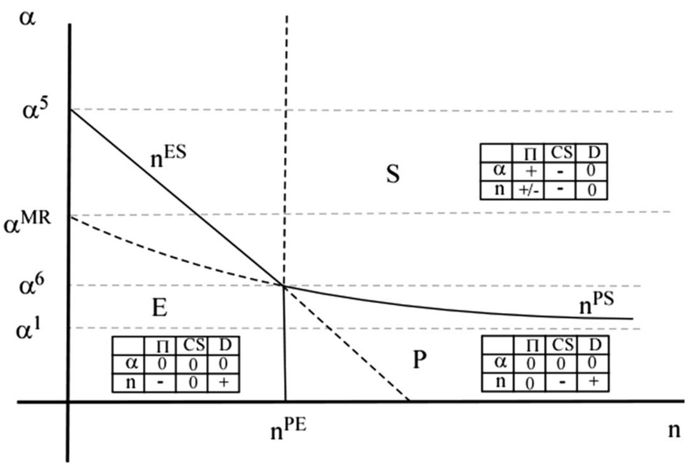

Fig. 3 Optimal strategies and their comparative statics with high *L* MB and $\alpha^4 > \alpha^5$

reduced under strategy S, but are unchanged strategy E. To reinstate equality of profit under each strategy it is necessary to increase the proportion of type L customers, which reduces profit under strategy E more than under strategy S. Similar logic can be applied to the position and slope of each of the two other curves in Fig. 3.

The results of the pairwise comparison of profits in Lemma 4 are used in Proposition 5 to identify the circumstances under which each of the pricing strategies is the most profitable:

Proposition 5 (Informal) *Assume $U^L > U_1^H$ and $\alpha^4 > \alpha^5$. The optimal pricing strategies for given combinations of (n, α) are shown in Fig. 3 as the sets P, S, and E bounded by the curves n^{PS}, n^{ES}, and n^{PE}.*

The reasoning to establish Proposition 5 is similar to that of Proposition 3. For example, Lemma 4 indicates that in the region in Fig. 3 above the curve n^{PS} and to the right of n^{PE} strategy S dominates strategy P and strategy P dominates strategy E. Thus in this region strategy S yields the greatest profits. Proposition 5 shows that each of the three possible pricing strategies (P, S, E) is optimal for particular sets of unbundling cost and distribution of customer types. As profit under strategy S is increasing with α, but is independent of α under both strategies E and P, strategy S is optimal for high values of α.

The following observation highlights the differences in CS and DWL among the pricing strategies:

Observation 2 For given combination of $0 \leq \alpha < \alpha^5$ and $n \geq 0$:

(a) CS is: (1) higher (lower) under strategy S than strategy P for $\alpha < \alpha^{MR}$ ($\alpha^{MR} < \alpha < \alpha^5$); and (2) higher under strategy P and strategy S than strategy E.
(b) DWL is lower under: (1) strategy P than strategy E; and (2) strategy S than either strategy P or E.

For instance, consider the comparison of CS under strategy S and strategy P. Under strategy P both customers pay U_1^H for a unit, so type L customers receive CS of $U^L - U_1^H$ while type H customers receive zero CS. Under strategy S, pricing is constrained by the prospect of unbundling for $\alpha < \alpha^{MR}$, and both customers receive CS that is equal to what they would receive if they paid a unit price that is equal to the unbundled price. As the unbundled price is less than U_1^H for $\alpha < \alpha^{MR}$, both customers receive a higher CS under strategy S than strategy P. Further, CS is zero under strategy E, and DWL is zero under strategy S.

The signs of the marginal changes in CS and DWL that follow marginal increases in α and n for each region in Fig. 3 are given in the tables in Fig. 3. For example, within region S an increase in the unbundling cost will reduce CS, as the unbundled price increases with α. Further an increase in n within region S reduces CS, as a higher proportion of customers are type H customers (who receive a lower CS than type L customers under strategy S). The tables within Fig. 3 and Observation 2 identify how profit, CS, and DWL vary with α and n.

Consider the ‘benchmark’ cases in which $\alpha = 0$ (linear pricing) and $\alpha \geq \alpha^5$. These benchmark cases under high L MB have received relatively little attention in the literature. In the $\alpha = 0$ case, strategy E is optimal for the firm for $n < n^{PE}$, and strategy P is optimal for the firm for $n > n^{PE}$. Hence profit is declining in n (while holding population constant) for $n < n^{PE}$ (as there are relatively fewer type L customers) and constant for $n > n^{PE}$ (as each customer generates the same profit). For $\alpha \geq \alpha^5$, strategy S is profit maximizing for all n. Profit is monotonically increasing (decreasing) in n for all n if profit per type H is greater (less) than profit per type L customer. This result is recorded as ‘±’ the table in region S of in Fig. 3.

Now consider how profit changes as a result of increases in n (while holding population constant) in the cases other than the benchmark cases. For $0 < \alpha < \alpha^{MR}$ profit increases with n under strategy S. From Lemma 3, under these values of α, type H customers each generate a greater profit than do type L customers. Therefore, in contrast to the benchmark cases, profit is non-monotonic in n for $\alpha^1 < \alpha < \alpha^{MR}$. However it is straightforward to show that, as in the case with intermediate L MB, profit is non-decreasing in α (as profit is independent of α under strategy E and increasing in α under strategy S).

In the benchmark case where $\alpha = 0$, CS is zero for $n < n^{PE}$ and $N^L(U^L - U_1^H)$ for $n > n^{MR}$. CS is zero in the benchmark case $\alpha \geq \alpha^5$ for all n. Now consider CS in regions other than those of the benchmark cases. A marginal increase in α (holding n constant) from a point within the region E or P shown in Fig. 3 does not change CS. However a marginal increase in α across the boundary n^{ES} or n^{PS} causes a positive jump in CS, as strategy S generates CS for $\alpha < \alpha^5$. Further increases in α cause CS to decline (as the unbundled price increases) until $\alpha = \alpha^5$, where CS is zero. CS is therefore higher within region S in Fig. 3 than in the benchmark cases; this is a result that is not readily extrapolated from examination of the benchmark cases alone.

In the benchmark case where $\alpha \geq \alpha^5$, DWL is zero because the firm conducts a separating strategy for all n. In the other benchmark case, $\alpha = 0$, DWL is positive for all n. In this case, as the firm adopts strategy E for $0 \leq n < n^{PE}$, DWL is rising in n because the proportion of customers that do not buy output (i.e., type H customers) is rising. Similarly DWL is rising in n for $0 \leq n < n^{PE}$, as type H customers do not consume a second unit under strategy P. From Observation 2, DWL jumps downward when $n = n^{PE}$.

Referring to Fig. 3, we see that for $\alpha^1 < \alpha < \alpha^5$ the relationship between DWL and n differs from that in the benchmark cases. For example, for $\alpha^6 < \alpha < \alpha^5$ DWL increases (from 0) as n rises from 0 to n^{ES} because the firm adopts the exclusion strategy. The DWL drops to zero for all $n > n^{ES}$, as the firm adopts the separating strategy in this region.

It is readily observed that the relationship between DWL and n therefore differs between the case of intermediate L MB and high L MB. It is also readily observed by reference to Fig. 3 that, in contrast to the results with intermediate L MB when $n > n^{MR}$, efficiency is monotonically non-decreasing in α.

5 Discussion

A key message of this paper is that one cannot always extrapolate from the well-studied benchmark cases, in which unbundling costs are either zero or arbitrarily high, to cases with 'intermediate' values of the unbundling cost. For instance, in contrast to the benchmark cases, with high L MB there is not necessarily a monotonic relationship between profitability and the distribution of customer types in the population.

However, with intermediate L MB, profit is monotonically increasing with the proportion of type H customers in the population. Again in contrast to the benchmark cases, there is not necessarily a monotonic relationship between efficiency and the unbundling cost. With intermediate L MB, efficiency is non-monotonic in the unbundling costs for high values of n ($n > n^{MR}$). This is because strategy S (which is efficient) is optimal for intermediate values of the unbundling cost, whereas exclusion strategies (which are not efficient) are optimal in the benchmark cases (as is shown in Fig. 2).

It was shown that consumer surplus is higher for intermediate values of the unbundling cost, whether there are one or two customer types (with either high L MB or intermediate L MB). Further, there are intermediate values of the unbundling cost for which a separating strategy is profit maximizing. With these values of unbundling cost, the use of non-linear pricing by the firm increases firm profit, consumer surplus, and efficiency relative to linear pricing; hence, such non-linear pricing represents a Pareto improvement over linear pricing.

Unbundling transfers surplus from the firm to the unbundler. Thus the firm's equilibrium pricing strategy prevents unbundling. While the prospect of unbundling output acts as a constraint on the firm's ability to conduct non-linear pricing, unbundling does not occur in the model. This finding suggests that the potential for unbundling has a curious implication for real world markets: it would constrain the actions of the firms, even though unbundling would be expected to be rarely—if ever—observed. Nonetheless, as suggested by the supermarket example, it is an important determinant of firms' pricing strategies.

The results have interesting empirical implications: the example of supermarket pricing referred to at the start of this paper, while puzzling from the perspective of the benchmark analyses, is readily explained using the analysis in this paper. Referring to Fig. 2, we can observe that, for intermediate values of α (the unbundling cost), pooling is optimal for low n (the ratio of the number of type H customers to the number of type L customers). However, a separating strategy is optimal for higher values of n. One might expect that, for goods such as canned fruit and vegetables, the dominant customer type will demand 1 unit at a time. On the other hand, soft drinks will have a high proportion of their consumers demanding a number of cans at one time.

This paper suggests two potential explanations for the observation that supermarkets only occasionally offer a discount for multiple purchases on particular items. In the context of this paper, this price change can be modeled as temporarily moving from a pooling strategy to a separating strategy.

The first potential explanation is that at various times of the year the proportion of type H customers in the population increases. By reference to Fig. 2, at these times it is possible that the supermarket switches from a pooling to a separating strategy.

The second explanation relies on the assumption that, by randomly timing of the discount for multiple purchases, the supermarket increases the unbundling cost. For instance, suppose that some households might consider jointly purchasing a bundled good. However, making the decision to undertake such a joint purchase involves a coordination cost, which is part of the unbundling cost. Randomly timing the offering of a 'discounted' bundle increases the coordination cost. The increase in coordination cost may be sufficient to deter households from joint purchases, thereby creating the opportunity (at the randomly determined times) to conduct the separating strategy (Figure 2 shows that the only switch from a pooling strategy that an increase in the unbundling cost can cause is to a separation strategy). A detailed empirical analysis would be required to determine the relative importance of these two explanations of the random timing of discounts for multiple purchases.

This second explanation is reminiscent of that proposed by Varian (1980) to explain sales. Varian argued that, by randomly timing price discounts, a firm could conduct price discrimination on the basis of consumers' differential access to information. The above explanation differs from Varian's in that the timing of sales increases coordination rather than information costs. Furthermore Varian's model is aimed at explaining the random reduction of the price of a given good, rather than the random timing of bundling. Clearly, however, these two explanations of the random timing of price changes are not mutually exclusive. Indeed, both mechanisms may be present in firms' actual pricing strategies. In this event, if the customers with low search costs were also those with low coordination costs, the two effects would reinforce the firm's incentive to undertake randomly timed price discounts.

Acknowledgments I would like to thank Bob Hammond, Ann Marsden, David Prentice, two anonymous referees, and the editor, Lawrence White, for useful comments on an earlier draft. All errors remain my responsibility.

References

Aguirre, I., & Espinosa, M. P. (2004). Product differentiation with consumer arbitrage. *International Journal of Industrial Organization, 22*(2), 219–239.

Alger, I. (1999). Consumer strategies limiting the monopolist's power: Multiple and joint purchases. *The Rand Journal of Economics, 30*(4), 736–757.

Armstrong, M. (1996). Multiproduct nonlinear pricing. *Econometrica, 64*(1), 51–75.

Calzolari, G., & Pavan, A. (2006). Monopoly with resale. *RAND Journal of Economics, 37*(2), 362–375.

Deneckere, R. J., & McAfee, R. P. (1996). Damaged goods. *Journal of Economics and Management Strategy, 5*(2), 149–174.

Gans, J. S., & King, S. P. (2007). Perfect price discrimination with costless arbitrage. *International Journal of Industrial Organization, 25*(3), 431–440.

Hammond, P. J. (1987). Markets as constraints: Multilateral incentive compatibility in continuum economies. *Review of Economic Studies, 54*(3), 399–412.

Maskin, E., & Riley, J. (1984). Monopoly with incomplete information. *RAND Journal of Economics, 15*(2), 171–196.
McManus, B. (2001). Two-part pricing with costly arbitrage. *Southern Economic Journal, 68*(2), 369–386.
Mussa, M., & Rosen, S. (1978). Monopoly and product quality. *Journal of Economic Theory, 18*(2), 301–317.
Rochet, J.-C., & Choné, P. (1998). Ironing, sweeping and multidimensional screening. *Econometrica, 66*(4), 783–826.
Varian, H. R. (1980). A model of sales. *American Economic Review, 70*(4), 651–659.
Zheng, C. (2002). Optimal auctions with resale. *Econometrica, 70*(6), 2197–2224.